EXHIBIT 4

Physicochemical Hydrodynamics

An Introduction
Second Edition

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6.4.3, the true velocity of the fluid at the surface must be zero from the viscous flow condition of no slip.

The four electrokinetic phenomena following the description of Shaw (1980) are

1. *Electrophoresis*—the movement of a charged surface plus attached material (i.e., dissolved or suspended material) relative to stationary liquid by an applied electric field.
2. *Electroosmosis*—the movement of liquid relative to a stationary charged surface (e.g., a capillary or porous plug) by an applied electric field (i.e., the complement of electrophoresis). The pressure necessary to counterbalance electroosmotic flow is termed the *electroosmotic pressure.*
3. *Streaming potential*—the electric field created when liquid is made to flow along a stationary charged surface (i.e., the opposite of electroosmosis).
4. *Sedimentation potential*—the electric field created when charged particles move relative to stationary liquid (i.e., the opposite of electrophoresis).

Both electroosmosis and streaming potential relate to the motion of electrolyte solutions and are therefore considered in the following section. However, we shall reserve the detailed discussion of streaming potential for the next chapter in connection with the treatment of sedimentation potential, which together with electrophoresis deals with the motion of dissolved or suspended charged particles.

(Probstein)

layer. [After Shaw, D.J. . London: Butterworths.

6.5 Electroosmosis

The discovery of electrokinetic phenomena may be credited to F.F. Reuss, whose experiments on electroosmosis and electrophoresis were described in 1809 in the *Proceedings of the Imperial Society of Naturalists of Moscow.* Reuss demonstrated that under the influence of an applied electric field water migrated through porous clay diaphragms toward the cathode. This is understood today to be a consequence of the fact, illustrated schematically in Fig. 6.5.1, that clay, sand, and other mineral particles usually carry negative surface charges when in contact with water; the water normally containing small quantities of dissociated salts. As described in the last section, the charged surface will attract positive ions present in the water and repel negative ions. The positive ions will therefore predominate in the Debye sheath next to the charged surface, so application of an external electric field results in a net migration toward the cathode of ions in the surface water layer. Due to viscous drag, the water in the pores is drawn by the ions and therefore flows through the porous medium.

Electroosmosis has been used in a variety of applications, including the dewatering of soils for construction purposes and the dewatering of mine tailings and waste sludges. It has also been used to characterize and design the salt rejection properties of reverse osmosis membranes and to help understand the behavior of biological membranes. Electroosmosis is also being investigated as a means of removing contaminants from soils.

diffuse double layer.

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